

# **ANALYSIS OF OBSERVATIONS OF COHERENT STRUCTURES IN THE OBL**

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## **LONG-TERM GOAL**

The long-range goal of this program is to understand the physical mechanisms which mediate the fluxes of energy, momentum, and matter between the air and sea. In particular, the form and dynamics of mixed layer motion can have a significant effect on these exchanges, and we hope to improve our ability to describe and predict these motions and their effects.

## **SCIENTIFIC OBJECTIVES**

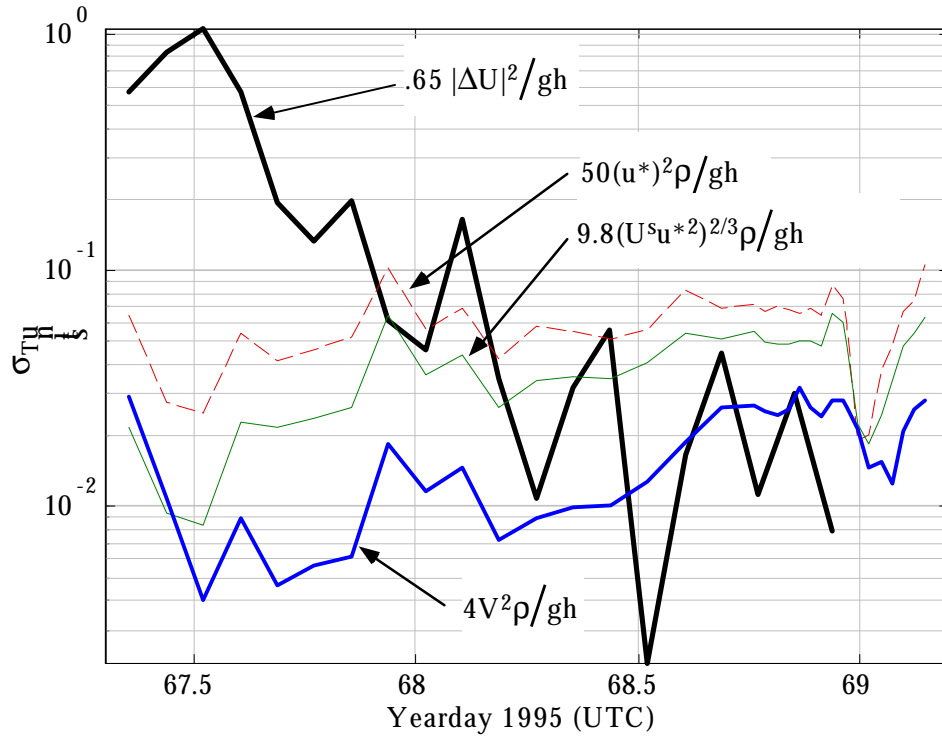
The immediate objective of this program was to document in some detail the motion at the surface over a variety of conditions, and relate this, together with the evolution of the mixed layer depth, to the measurable forcing terms (wind, waves, inertial currents, heat-flux, and stratification).

## **APPROACH**

A Phased-Array Doppler Sonar (PADS) was deployed on the Research Platform FLIP off Pt. Conception in the spring of 1995, as part of MBLEX, an experiment aimed at improving our understanding of the Marine Boundary Layers on both side of the air/sea interface. A second was completed in time for the second leg of MBLEX, off Monterey CA. This instrument provides estimates of the radially-directed component of velocity over an area up to 400m radius by 35 degrees in azimuth. The spatial resolution is about 8 m in range by 3 degrees; so (for example) at 200m range the sample area is about 8 by 10 meters. The sonars transmitted every 0.75s, with each ping simultaneously sampling over all angles; thus surface waves as well as the mean flow are resolved in the raw data. 30s averages (40 pings) were recorded, providing about 3 cm/s RMS velocity error in each range-angle bin (in practice, additional errors arise from imperfect beamforming, etc.). All data were coordinated via GPS time-stamping. This enabled detailed comparisons between the quasi-continuous coverage from the PADS and the presumed forcing by wind, Stokes' drift, inertial currents, and stratification.

The approach taken in this project is to compare the measurements from leg-1 of MBLEX to a simple "PWP" type mixed layer model, and to a similar model augmented by a "Langmuir circulation" parameter (Price et al. 1986, Li and Garrett 1997). Work on the CTD data (density profiles) and current profiles has been in collaboration with R. Pinkel and student M. Alford. Wind stress calculations for the first MLBEX leg were carried out by then-student K. Rieder (supported under the AASERT listed here).

## **WORK COMPLETED**



**Figure 1.** Mixing strength, parameterized by the density jump required to stop mixing, for (i) the bulk Richardson mechanism (thick line); (ii) Langmuir circulation, as estimated directly from the RMS velocity scale  $V$  (medium line); and (iii) LC mixing estimated from  $U^s$  and  $n_t$  via comparison with numerical model results, for developing waves (thin solid line) and for fully developed waves (thin dashed line).

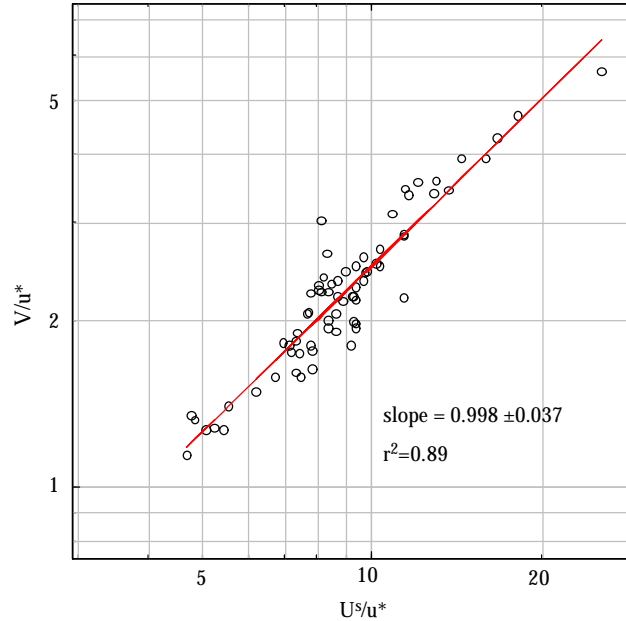
Both legs of MBLEX were successful. The data are both novel and high quality. Almost all relevant forcing terms were well measured (with the exception of the radiation terms in the heat balance).

Data quality control and analysis have gone well. The analysis of MBLEX leg-1 is essentially complete. The results described below have been written up and have been accepted for publication.

## RESULTS

- The observed mixed layer deepening is consistent with the “bulk dynamics” of shear across the thermocline due to inertial motion as the primary agent. Surface stirring by the combined action of wind and waves may have helped maintain the mixed layer after this, and may even have induced some additional slow deepening, but is clearly of secondary importance (figure 1).
- The surface velocity variance associated with the mixing, as observed here, is considerably smaller than in previously reported cases. It is suggested that this may be related to swell opposing the wind.
- When there is Langmuir circulation, the RMS velocities associated with the low-frequency features scale quite tightly with the Stokes’ drift alone, rather than with the wind or a combination of wind and waves (figure 2). This relation is nonlinear in that a threshold must be set for the existence of Langmuir circulation before it holds.

- Langmuir circulation can vary significantly in strength, spacing, and peakiness over timescales of order 15 minutes (figure 3). Not the wind, waves, nor mixed layer depths vary significantly on this time scale. In these “vacillations,” the strengths of velocity versus intensity features were 180° out of phase: strongest intensity features coincided with weakest RMS velocities. It is suggested that the buoyancy of bubbles may be non-negligible in the dynamics of these phenomena.
- The spacing and orientation of intensity versus velocity features near the surface can differ. For the data studied here, intensity features aligned within a couple degrees of the wind (favoring the right), while the velocity features averaged 10° to the right of the wind. The intensity spacing tracks 2 times the mixed layer depth, while the velocity feature spacing is closer to 2.5 times MLD. While this mismatch is



**Figure 2.** Scaling of the RMS measured radial surface velocity takes the general form  $V \sim u^*(U^S/u^*)^n$ . The value of  $n$  is sought as the slope of  $(V/u^*)$  versus  $(U^S/u^*)$  on a log-log plot. This figure indicates a well-determined value for  $n$  very near 1.0; i.e.,  $V \sim U^S$ , with no dependence on  $u^*$  once Langmuir circulation is well formed. Values before yearday 67.66, when there were no signs of Langmuir circulation, were excluded from this plot.

puzzling, it would appear likely that the time/space-dependent behavior of bubbles in a time-varying flow should be investigated. Simulations with realistic bubble dynamics may help to understand these differences.

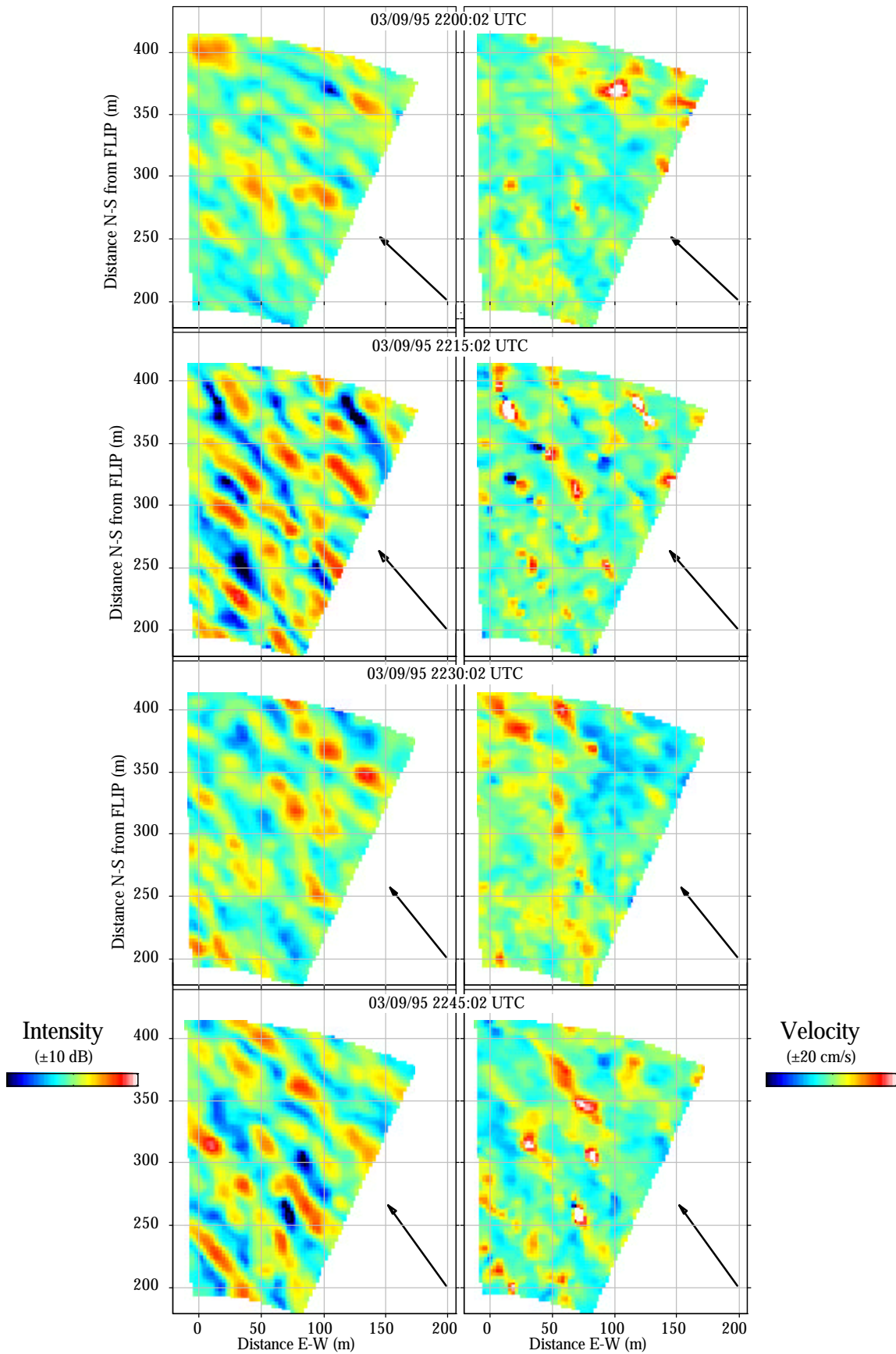
- The difference between mean feature-tracking and Doppler velocity estimates provides a reasonable and direct estimate of the Stokes’ drift near the surface. A unique aspect is that both estimates come from the same data stream, without explicitly resolving the waves.

## IMPACT/APPLICATION

Parameterization of the mixed layer behavior is likely to be improved by incorporation of some of the results shown here.

## TRANSITIONS

The PADS technology has been improved and extended, and a pair of PADS were deployed subsequently as part of a SandyDuck project.



**Figure 3.** Four frames 15 minutes apart during strong forcing conditions. Note how the stripes alternate between well-defined and irregular. The arrows indicate the wind; a 50 m vector (on the image's scale) represents a 10 m/s wind. North is up.

## **RELATED PROJECTS**

Below I list some of the related work and collaborations.

- 1- Wind stress and wave effects. Collaborations with C. Friehe (UC Irvine) and with J. Edson (WHOI).
- 2- Comparison of current profiles from our up/downlooking sonar with the ADV of D. Checkley. Also some comparisons of our respective “LC indices.”
- 3- Comparisons of the observed form of surface flows with of models of S. Leibovich and of J. McWilliams (etc.- this list may grow).

## **REFERENCES**

Li, M., and C. Garrett, Mixed layer deepening due to Langmuir circulation, *J. Phys. Oceanogr.*, 27, 121-132, 1997.

Price, J. F., R. A. Weller, and R. Pinkel, Diurnal Cycling: Observations and models of the upper ocean response to diurnal heating, cooling, and wind mixing, *J. Geophys. Res. Oceans*, 91, 8411-8427, 1986.